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FINAL REPORT

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EFFECTS OF LONG WAVES ON THE GENERATION OF WAVES BY WIND

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Final Report

Program Objective:

- A quantitative understanding of the properties of the short wind generated waves relevant to the interpretation of remote sensing radar images of the ocean. To that effect, the work has focused on the interaction between long and short waves in the presence of water and wind shear.

Significant results:

- Clarification of issues associated with the dynamics of short surface waves in the presence of shear, swell and wind. These results are of importance to ocean remote sensing applications because sensitivity of short wave response to swell is an efficient mechanism for surface manifestation of subsurface disturbances.
- It is found that in the presence of finite amplitude long waves, superharmonic wind generated wave perturbations are stabilized if the swell moves with the wind or current. The instability tends to be enhanced for long waves propagating in a direction opposite to the wind.
- For the case were the infinitesimal wave perturbations are sidebands of the finite amplitude short carrier wave, the effect of shear in the instability is also substantially different if the finite amplitude waves move along or against the shear. In this case, depending on the ratio of long to short wavelength and vorticity, the instability growth can be enhanced or reduced. In most cases as the shear strength increases the instability is first enhanced and later suppressed.
- Nonlinear three-wave interactions between two short near capillary waves and a long gravity wave in the presence of shear have also been investigated. Regions of pump-wave instability where the short waves can have very large growth (explosive) at the expense of the long wave have been identified.

Effects of Long Waves on the generation of waves by wind

Final Report

Papers:

- Effect of wind profile on the instability of wind blowing over water, Morland, L. C. and Saffman, P. G. 1993. J. Fluid Mech., 383-398.
- Effects of long waves on the stability of wind generated waves. M.Z. Caponi, P.G. Saffman, H.C. Yuen. Proceedings of "The Air-Sea Interface" M.A. Donelan, W.H. Hui, W.J. Plant, (eds.), 1993, University of Toronto Press.
- The growth of wind waves at the crest and trough of a low amplitude swell. L.C. Moreland and P. Saffman, 1997, J. Fluid Mech, to appear
- Effect of wind and shear on surface waves, M. Z. Caponi and P. G. Saffman, 1996, Naval Research Reviews, 3/XLVIII, 63

Presentations:

- Effects of long waves on the stability of wind generated waves, by M.Z. Caponi, Air-Sea Interface Symposium, June 1993, Marseille.
- Effect of long waves and shear on the generation of waves by wind, by M. Z. Caponi, ONR ocean waves workshop, Tucson, Arizona, March 1994.
- Shear effect on water waves. by P. G. Saffman, ONR ocean waves workshop, Tucson, Arizona, March 1994.
- Bifurcation phenomena in finite amplitude water waves. Invited presentation by P. G. Saffman H.B. Keller 70th Birthday Symposium. Caltech Dec 1995.
- End of year report to ONR, M.Z. Caponi and P. G. Saffman, July 1996.

Papers in preparation and submitted to refereed journals:

- Modulation of Gravity Waves with Shear in Water. A. Baumstein and P. G. Saffman. Submitted to Applied Mathematics. *The effect of water shear on the stability of infinitesimal perturbations (in the form of sidebands) to a finite amplitude gravity wave is investigated both numerically and analytically. The shear is modeled by a piecewise-linear velocity profile. A nonlinear cubic Schroedinger equation for the wave envelope of a slowly varying wave train is derived.*

Depending on the direction of propagation (along or against the shear) of the finite amplitude waves, the effect of shear on the stability is substantially different. In most cases, however, the shear strength increase first enhances, but later suppresses the instability.

- Steady Non-Symmetric Gravity waves with Shear in Water. A. Baumstein and P.G. Saffman, submitted to J. Fl. Mech. *A new type of the steady two- dimensional inviscid gravity waves with shear is computed numerically. These waves appear at relatively low amplitudes and lack symmetry with respect to any crest or trough. A boundary integral formulation is used to obtain a one-parameter family of non-symmetric solutions trough a symmetry-breaking bifurcation.*
- Effect of very long waves on short wind generated waves stability for piece wise wind profiles. M. Caponi In preparation, to be submitted to J. Fl. Mech. *A model has been developed that assumes a very slow variation of the long waves relative to the short waves and piecewise profiles. It permits to obtain an analytical solution for the system eigenvalues and hence a simple calculation of the parametric dependence of the short wave growth with shear and long wave characteristics. It is found that the short waves steepen near the crest and flatten near the trough of the swell, in agreement with experimental results.*
- Stabilization of wind generated waves by longer waves and shear. M. Caponi, in preparation to be submitted to J. Fl. Mech. *An approach is developed to investigate the effect of pre-existing wind generated waves on the stability of shorter wind generated waves in the presence of wind and water shear. The method, that assumes a Fourier decomposition of the displacement perturbations, yields a general dispersion relation that describes the interaction between the different modes. The dispersion relation is amenable to a simple numerical solution for the case of interaction between 2 modes. Results agree with previous analysis that show stabilization of short wave growth in the presence of finite amplitude long waves propagating along the wind direction.*
- Effect of nonlinear interactions in wind generated waves with shear. M. Caponi, in preparation. *An approach has been developed that describes the nonlinear interaction between water waves in the presence of wind and shear. The description, a generalization of the Zakharov approach, has been carried out to third*

order (4 wave interaction) and assumes a piece-wise wind profile. It permits to calculate the effect of a finite bandwidth spectrum. In the limit of a single mode finite amplitude long wave and an infinitesimal short wave perturbation the result agrees with our previous calculations.

Thesis projects by graduate students:

Nonlinear Water Waves with Shear. By A. Baumstein (summer 97).

Thesis Abstract: Various aspects of nonlinear inviscid gravity waves in the presence of shear in the air and water are investigated. The shear, which appears due to the presence of wind in the air and current in the water is modeled by a piecewise linear velocity profile.

The interaction of short and long gravity waves is studied numerically, using spectral methods, and analytically, using perturbation methods. Special attention is paid to the verification of observations and experimental results. It is confirmed that for finite amplitude waves propagating in the same directions as wind or current, the superharmonic infinitesimal perturbations are more stable than for the case of waves moving against wind or currents.

Infinitesimal perturbations in the form of sidebands are also investigated numerically and analytically. The nonlinear cubic Schroedinger equation for the wave envelope of a slowly varying wave train is derived. It is shown that depending on the direction of propagation (along or against the shear) of the finite amplitude waves, the effect of the shear on the stability is substantially different. In most cases, however, the shear strength increase first enhances, but later suppresses the instability.

Three-wave interactions of gravity waves with shear in the water are considered. The interaction equations are derived with the help of two different perturbation approaches. The question of stability is addressed for both resonant and near-resonant interactions. The regions of explosive and "pump-wave" instability are identified for various types of three-wave interaction.

A new type of steady two-dimensional gravity waves with water shear is computed numerically. These waves appear at relatively low amplitudes and lack symmetry with respect to any crest or trough. A boundary integral formulation is used to obtain a one-parameter family of non-symmetric solutions trough a symmetry-breaking bifurcation.

Inviscid instability of continuous shear profiles at an air-water interface. By D. Hill.

The stability for water waves in the presence of wind and shear (in the air and water) has been calculated for smooth wind profiles and the results compared with those for stick wind profiles. It was found that the stick wind profile is a good approximation to obtain qualitative behavior. The results present some differences in the quantitative values of the growth rates.

Honors/Awards/Prizes:

P.G. Saffman. Otto Laporte Memorial Award, American Physical Society. November 1994. Fluid Dynamics Award. American Institute of Aeronautics and Astronautics. June 1995.